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14. ABSTRACT
Cooperative signal processing is a promising technique to enhance system performance by employing virtual antenna arrays. In communications, cooperative transmission exploits space diversity via spatially separated relay nodes. Performance of such systems can be further improved by resource optimization. In this research, we investigated various factors influencing the resource optimization solutions and results in terms of the system error performance and throughput. Partly inspired by the benefits of cooperative communications, cooperative sensing is drawing increasing interests recently. In such systems, a particularly critical issue is the waveform optimization among the cooperative nodes. In this direction, we developed the optimum and robust waveform designs respectively, and established the intrinsic connections between the mutual information (MI) and mean square error (MSE) measures in the sensing context. The sensitivity analysis for the optimum designs is also carried out.

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FY09 Year End Report

WIRELESS COOPERATIVE NETWORKS: SELF-CONFIGURATION AND OPTIMIZATION

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A Abstract

Cooperative signal processing is a promising technique to enhance system performance by employing virtual antenna arrays. In communications, cooperative transmission exploits space diversity via spatially separated relay nodes. Performance of such systems can be further improved by resource optimization. In this research, we investigated various factors influencing the resource optimization solutions and results in terms of the system error performance and throughput. Partly inspired by the benefits of cooperative communications, cooperative sensing is drawing increasing interests recently. In such systems, a particularly critical issue is the waveform optimization among the cooperative nodes. In this direction, we developed the optimum and robust waveform designs respectively, and established the intrinsic connections between the mutual information (MI) and mean square error (MSE) measures in the sensing context. The sensitivity analysis for the optimum designs is also carried out.

B Technical Results

Resource Optimization in Cooperative Communications

We investigated the resource optimization problem in cooperative communications for four commonly adopted relaying systems: the amplify-and-forward (AF) protocol with coherent or differential modulation, and the decode-and-forward (DF) protocol with coherent or differential modulation. The closed-form symbol error rate (SER) and outage probability (OP) performances are derived for all four systems. Based on our previous work, we know that the location optimization is an important technique for system performance improvement. Therefore, location optimization is carried out for all four cooperative systems using both SER and OP optimization metrics. The comparisons among the optimization solutions and results for all four systems with both metrics revealed the influence of different system parameters, which can be used to guide the optimization strategy selection in practice. The comparison results are summarized as follows.

Optimization Metric: Even though SER and OP evaluate the system performance from two very different aspects, the four systems surprisingly share the same optimization solutions. This suggests that SER and OP are identical from the resource optimization perspective;

that is, the SER-optimized relay system is also OP-optimum. On the other hand, while SER can be formulated in closed- form for arbitrary number of relays, the OP is only available for single-relay AF systems. Therefore, SER is a more convenient metric for resource optimization in cooperative systems with arbitrary number of relays.

Modulation Type: Regarding different modulation types, the coherent and differential systems have similar performance with identical diversity gains, leading to identical optimization solutions. This observation implies that the optimized coherent system can also adopt differential modulation with the same system setting while still achieving the optimum performance.

Relaying Protocol: On the other hand, with the same modulation type, AF and DF protocols result in very different optimization results. However, this difference decreases as L increases. We also observe that, in AF systems, the relay-destination link is more critical than in DF systems. Hence, for the same system setup, the optimized AF systems require relays to move closer to the destination than DF systems.

Waveform Optimization in Cooperative Sensing

Information theory, and particularly the MI, has provided fundamental guidance for communications research. However, the practical meaning of MI in the sensing context remains unclear to date. Previous work shows that under the white noise assumption, the optimum water-filling scheme simultaneously maximizes the MI and minimizes the estimation minimum mean square error (MMSE). Such an equivalence, however, does not hold when the target parameter statistics are not perfectly known. To further the understanding of the practical meaning of MI and to establish a connection between the MI and commonly adopted MSE measures for cooperative sensing, we consider the general colored noise, incorporate the normalized MSE (NMSE), and develop joint robust designs for both the transmitter (waveforms) and the receiver (estimator) under various target and noise uncertainty models. Our results show that: i) the optimum waveform designs resulted from the MI, MMSE and NMSE criteria are all different; and ii) compared to MMSE, the NMSE-based designs share more similarities with the MI-based ones, especially when the target and noise statistics are not perfectly known.

Since the optimum waveform designs depend on the ideally known target power spectrum density (PSD) assumption, a small target PSD error might introduce huge disturbance

to the optimum designs. The robustness of our optimum designs and the sensitivity comparison among the three criteria consist of an intriguing problem. In order to address these issues, we perform the error sensitivity analysis not only at the multiple cooperative nodes in terms of the waveform designs, but also at the receiver in terms of the overall estimation performance. The analyses show that the NMSE-based waveform design solution is relatively more sensitive than its MMSE- and MI-based counterparts. At the receiver side, the NMSE performance is compared among the three criteria. While all three criteria do not show significant performance deterioration, the NMSE-based design is affected most around the PSD error threshold, which is consistent with the results obtained at the cooperative nodes.

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